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Questions Asked During Command Language Learning: Implications for Knowledge Representation

Merryanna L. Swartz

Instructional Technology Systems Technical Area
Training Research Laboratory

U.S. Army

Research Institute for the Behavioral and Social Sciences

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This paper discusses an investigation into the psychological role of question asking during a procedural learning task. Questions were interpreted using a conceptually based context-dependent model. Data was collected in a learning-by-doing paradigm following a socratic-like tutoring session and analyzed using this interpretation model. The kinds of questions asked during learning are descriptive of the knowledge state for the questioner at a given point in the tutoring/learning situation.

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20. Abstract (Continued)

Results indicate an emergence of a pedagogically functional question set inherent to the domain skill. A cluster of three question types appears to function as the main method for acquiring and understanding knowledge during the early stages of learning. Questions were found to be articulated at the boundaries of strategy shifts as subjects evaluated their problem-solving methods for achieving solutions in the problem space for the task. These results may have implications for defining student models, for creating more effective dialogue systems in intelligent computer tutors, and for improving instructional strategies.

Technical Report 740

Questions Asked During Command Language Learning: Implications for Knowledge Representation

Merryanna L. Swartz

Instructional Technology Systems Technical Area
Zita M. Zimutis, Chief

Training Research Laboratory
Jack H. Hiller, Director

U.S. ARMY RESEARCH INSTITUTE FOR THE BEHAVIORAL AND SOCIAL SCIENCES
5001 Eisenhower Avenue, Alexandria, Virginia 22333-5600

Office, Deputy Chief of Staff for Personnel
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FOREWORD

Computer-based training in the Army has been around for quite some time; however, new advances in computer capabilities will allow for even more sophisticated human-computer interaction than before. One example is interactive student-tutor or mixed initiative dialogues in computer tutors. While the promise is present, the reality of such an interface requires further investigation. Natural language processing requirements for such an interface and the accurate interpretation of student questions by the tutor is one step in the direction of refining such a capability. The results of this work will provide insight into the psychology of natural language processing and instructional strategies useful for developing improved training.

Army trainers and developers of advanced computer tutors will ultimately profit from this work as we at U.S. Army Research Institute begin to discover the requirements for optimal human-computer interaction.

Edgar M. Johnson

EDGAR M. JOHNSON
Technical Director

QUESTIONS ASKED DURING COMMAND LANGUAGE LEARNING:
IMPLICATIONS FOR KNOWLEDGE REPRESENTATION

EXECUTIVE SUMMARY

Requirement:

The U.S. Army Research Institute for the Behavioral and Social Sciences (ARI) conducts research in support of new technologies for Army training. One particular problem is that of effective human-computer interfaces. This report on the natural language processing requirements in tutorial dialogues provides information that will be useful for developers of such interfaces.

Procedure:

The author of this report is conducting protocol analysis of student-generated questions in a computer tutor-like learning situation. The research has developed and tested an interpretation model for the questions to allow the tutor/teacher to describe the student knowledge state.

Findings:

A specific functional question set appears to have emerged in the domain of procedural skill learning. A tripartite of question types function as information gatherers and structural organizers for the domain knowledge during early learning. Articulated questions about a specific problem during learning seem to activate associated knowledge that becomes available for solving and reasoning about the problem.

Utilization of Findings:

The purpose of this report is to describe the basic cognitive parameters involved in student questions asked during tutorial dialogues. These results will provide a basis for development of a psychological theory of question asking as a metacognitive process during learning. Further, this work will lead to understanding the natural language requirements necessary to develop a tutorial dialogue interface.

QUESTIONS ASKED DURING COMMAND LANGUAGE LEARNING:
IMPLICATIONS FOR KNOWLEDGE REPRESENTATION

CONTENTS

QUESTIONS ASKED DURING COMMAND LANGUAGE LEARNING:
IMPLICATIONS FOR KNOWLEDGE REPRESENTATION

INTRODUCTION

Recent advances in computer technology have increased the need for people to acquire computer skills in order to function in a rapidly developing computerized society. Users interact with computers for a variety of reasons: performing tasks, solving problems, and learning new computer skills. Learning command languages, for example, those used for word processing, database, and spreadsheet applications, has recently become required in automated environments. Investigation into the learning process that occurs when one acquires these skills can serve several purposes useful for understanding human-computer interaction.

Card, Moran, and Newell (1984) propose a theoretical framework, GOMS (goals-operators-methods-selection), for representing the hierarchical goal structure for complex cognitive skills. According to this theory, the cognitive structure for the skilled behavior consists of the four components in the model. However, the GOMS model is a theoretical construct that deals only with well-learned skills. Along the continuum of learning, novices rely heavily on general problem solving behavior for performing tasks until an adequate database and structure for the knowledge is acquired (Anderson, 1982, 1985). The transition made from a problem-solving model to a GOMS model during learning, however, is poorly understood. Studies investigating the change in strategies in a learning by doing paradigm (Anzai & Simon, 1979; Card, Moran, & Newell, 1984) have shown that skilled behavior is the result of practice and experience with the task. However, more information is needed to better understand this process and how the knowledge is represented. How much and what type of domain knowledge is needed to select the appropriate method to accomplish a task? How much practice is needed before the correct selection rules are recognized to control search over the problem space? When in the learning process does skilled behavior begin to emerge? What kind of instructional feedback should be offered and when to optimize learning? The answer to these questions can be found by looking at the nature of questions themselves: questions asked during skill acquisition.

During learning, students will ask questions to obtain the information they need in order to understand the task. However, there currently exists no psychological theory of question asking. One approach toward developing a theory of question asking is to study and classify the types of questions and their function within a particular system. Harrah (1973) points out that one learns the question system relevant to ones field of specialization. Consider the questioning systems in law, medicine or science.

In instructional science, questioning can be useful for guiding the student toward a particular logic or approach to the subject matter. I believe that the investigation of student question asking will provide useful information for understanding how skills develop during procedural learning. Evaluation of

the kinds of questions asked that comprise a question set for a particular domain should provide information that is descriptive of the knowledge state, the goals, operators and methods a student needs at a given point in time to perform some task. As the skill behavior becomes more practiced, the types of questions a learner asks should differ as a function of the knowledge acquired. In early learning, the temporal placement of the question in relation to performance may reflect the nature of the search control strategies attempted during the task as different problem solving methods are applied to the problem space for the task. As search control develops into more precise selection rules for the domain, this temporal placement will no longer have significance and the question may disappear altogether.

This paper presents a model of an analytical methodology for interpreting questions generated in procedural skill learning. The focus is on knowledge representation in the very early stages of procedural skill acquisition in a situational learning by doing paradigm. The first section introduces the concept of pedagogical question asking and understanding the function of these utterances during a learning task. Next, a description of the interpretive method is presented to illustrate how the study of the conceptual analysis of questions can help psychologists better understand how knowledge is organized during the acquisition process. The second section of this paper discusses the nature of the domain knowledge, a representational framework for the knowledge, a popular spreadsheet command language. The last part of this section presents a brief overview of the processes and strategies employed by novices in procedural skill learning. The third section discusses how questions might function as probes in memory and argues for the utility of the interpretation model for describing knowledge states within a particular representation for the knowledge. The final section presents empirical evidence and discussion of the results from a preliminary investigation employing the proposed model for question interpretation in a procedural learning task.

PEDAGOGICAL QUESTIONS AND DISCOURSE

Much of human behavior is goal-oriented in language communication. Conversational goals can serve many purposes: getting information, imparting information, amusement, or simply to pass the time. Questions are a type of speech act that can also be goal-based (Belnap & Steel, 1976; Hobbs & Robinson, 1979). In natural language discourse, questions are asked for many reasons and can take many forms. I am concerned here with what Harrah (1973) calls pedagogical questions, questions that can provide instructional information to the questioner when answered.

In a learning situation, students will ask questions to obtain the information they need in order to understand the task. Questions are asked for a variety of reasons and can serve many purposes. For example, consider the questions novice users of computer systems might ask when learning a new skill on the computer. Presumably students are motivated to ask a question because of the need for instructional information regarding system or task use. In procedural skill learning, they can serve to gain understanding about new concepts, new procedures, and causal relationships in the domain. From a psychological view, the study of these pedagogical questions may provide information concerning the contents and organization of information in memory during skill

acquisition. Indeed, Norman (1979) theorized that the investigation into one's ability to ask questions can be useful for understanding mental strategies used to access the memory system. Educators are often heard to lament that their students never ask any questions. However, this is not always true, and the educator may learn a great deal about what the student knows from the study of student-generated questions. In fact, educators often use questions as an instructional strategy to evaluate learning (Collins & Stevens, 1983; Harrah, 1973). Encouraging students to formulate questions about what they are learning can develop into a useful strategy for understanding the subject matter because it fosters constructing and evaluating hypotheses about the meaning of the material (Collins & Brown, 1986). Miyake and Norman (1979) were the first to state that the ability to ask questionsis based on the function of appropriate knowledge structures and the level of completeness of these structures. However, at the time of their study, there existed no useful method with which to analyze and interpret the student-generated questions. There currently exists no psychological theory of question asking (Harrah, 1973; Belnap & Steel, 1976; Norman, 1979), therefore, I am hopeful that the results from this study will generate useful data for understanding the nature and purpose of questions in a learning by doing paradigm for procedural skills.

Socratic tutoring is based on the use of questions to stimulate students' reasoning about certain concepts (Collins, 1977). Understanding question asking is an important issue for creating intelligent tutors wherein both the tutor and student can ask questions to clarify new concepts, student performance, and thereby improve both learning and instruction. Development of dialogue systems in computer tutors could improve instruction by allowing the student and teacher/tutor to engage in mixed-initiative question asking for improving understanding. Recent work on questions has focused on question answering in prose comprehension (Graesser, 1985) and in artificial intelligence question-answering and intelligent tutoring systems (Collins, 1977; Lehnert, 1978; Burton & Brown, 1979; Sammut & Banerji, 1986). As a result of some of this work, an analytical method based on conceptual categories was developed that interpreted questions by decomposing the question particle and remaining proposition of the utterance within the context of the query. Little work has been done on human question generation and its implication defining knowledge representation using such an analytical method. None has been done in the context of learning procedural skills.

Analysis of questions as speech acts can be difficult if the goal is not clear from the utterance, the context is unknown, or if multiple inferences can be interpreted (Hobbs & Robinson, 1979; Belnap & Steel, 1976). Here I address questions that are not uniquely conversational in context but take on a pedagogical motivation. By this I mean that the context of the questions generated is defined by the learning environment and nature of the skill behavior required of the learner performing some task. Because of this well-defined context, the instructional environment will necessarily direct the goals lying behind any speech act. During learning of a procedural skill such as command languages the first two interpretive problems of goal clarity and context will be obviated by the nature of the task. This point will be discussed in more detail in the section on command language learning that follows. Because the learners are naive to the domain, the most obvious general goal for their questions will be to locate information in order to accomplish and understand a

specific task or knowledge element in the domain. The particular time within an instructional sequence that a question is posed will further define its goal based on what the student knows and what needs to be learned next in the lesson. Thus, only multiple inferences for each utterance remains a potential concern in the interpretation process for understanding the meaning of pedagogical questions. Still, this problem alone can impose significant difficulty in any attempt on interpretation.

Nevertheless, borrowing from the work done by artificial intelligence researchers, I feel that an existing methodological approach to interpret utterances using a conceptualization scheme to classify questions will help psychologists understand the nature of question asking during learning. Components of a methodology that can reveal the conceptual representation of a query in relation to the contents of the utterance are presented below.

ANALYTIC METHOD FOR QUESTION ASKING

Conceptual Question Categories

The learner who attempts to accomplish some task but does not know the appropriate goal structure, actions, or operators to use can ask a question to ellicit the required information. For instance, how to accomplish a goal if the correct procedure is unknown, soliciting the definition of certain commands, verifying system operators, testing hypotheses regarding proper procedures, or clarification of solution strategies. It seems only logical that this question, when analyzed for its semantic contents and meaning, will be linked to the spot in the accessed knowledge structure that this missing this information. Research investigating a conceptual representation for questions in question-answering systems has attempted to resolve some of the issues related to understanding natural language queries. However, several problems remain: understanding the meaning of a question, knowing how the context affects understanding, selecting appropriate responses, and searching memory for the response. A theory of question answering by Lehnert (1974) has identified thirteen question conceptual categories that have been assessed for their validity in interpreting certain knowledge concepts from question utterances. They are:

1. causal antecedent

2. goal orientation

3. enablement

4. causal consequent

5. verification

6. disjunctive

7. procedural

8. concept completion

9. expectational

10. judgement

11. quantification

12. feature specification

13. requests

She has developed and implemented a computer program that can generate plausible answers to questions formulated from these categories. This is akcomplished through a symbolic procedure for specifying the world knowledge structures it searches to obtain the answers. Specific rules are applied to the question when placing it into the appropriate category. For example:

Do you push this key to delete?
(Verification question requiring a yes-no response)

The questioner is asking about a particular operator (a key) he thinks can be used to delete, but seeks clarification through asking a verification question.

The result of applying this conceptual categorization methodology renders the utterance language independent for further interpretation. The conceptual representation provides a formalism that can then be used to extract the meaning from the utterance. Lehnert cautions that applying this method does not result in complete understanding of the question. In fact, during question interpretation, all parts of the proposition must be analyzed together.

Graesser (1985) proposes a procedure for interpreting questions to locate appropriate answers from the knowledge base or memory. He incorporates Lehnert's conceptual category procedure for interpreting the question particles and adds another procedure to interpret the remaining utterance or propositional unit. While his work focuses on question answering, the methodology he employs for question interpretation is appropriate for understanding the nature and representation of questions asked and for tracing the path of the knowledge element sought by the query in the knowledge structure.

According to this approach, each question phrase is analyzed by identifying the question particle and placing it into a question concept category to reflect the intent of the question: causal, procedural, feature specification and so on. The propositional unit is the remainder of the sentence after the question particle is removed. Next, this propositional unit is divided into two components, the first of which, the statement element, is categorized into a number of classification types to reflect the context or main idea expressed by the proposition. The second component of the proposition is the unknown element of the question or what Graesser terms a knowledge element. The knowledge element refers to the kind of information the questioner wants to have.

Question Asking Interpretation Model

The method for interpreting the questions in this study is based on Graesser's model to decompose the question phrase into the following form:

(<Question Particle><Propositional Unit>)

(<Question Type><Context><Knowledge Node>)

Lehnert's categories will be used to interpret the question particles, the first element in the interpretation model. In discourse, propositions express the main idea the communicator wishes to impart in the utterance. In selecting a classification scheme that would best convey the ideas central to question asking in procedural skill learning, the nature of the domain, command languages, was considered. Given this domain, I have chosen three classification types that I feel describe the context of the propositional unit when interacting with the problem space presented by the task: goal, action, and state. The propositional context is the second element in the interpretation model.

A cognitive task analysis for the domain based on the GOMS model (Card, Moran, & Newell, 1983) was used to describe the structure of the knowledge. I will present a brief overview of procedural skill learning and a theoretical framework for organizing such knowledge after it develops into a practiced cognitive skill in the following section. The point is raised here to establish the rationale for selecting the three classification types for the context in the propositional unit used in this model. Learners begin acquiring some skill using problem solving strategies, thus we can think of the propositional contexts as a kind of problem space for the utterance. Since acquisition of task goals are important to procedural skill learning as are acquiring a set of correct operators necessary to perform certain acts in the domain, the first two main ideas I expected to find expressed in the utterances included those referring to task goals and actions.

Goal problem space contexts include questions about task goals and subgoals. Action problem space contexts include questions that refer to operators or operations required to accomplish a specific procedure or action. The third classification type selected was state space since problem solvers are constantly evaluating states as they search for the correct solution path. State problem space contexts refer to any question about a state transition in the system that results after some operator has been applied to some existing or current state or a particular goal has been obtained. Since there may be a merging of two kinds of knowledge in this task, the domain knowledge of the command language itself, and the device knowledge for the computer system, learners may have questions that refer to a particular state transition that could be part of either system. Therefore, the state problem space context may refer to either a goal state, action state or system state transformation.

The third element in the interpretation model is the knowledge node. Knowledge sought by the query will be classified into general schema-like nodes for the domain. These nodes should reflect the broad clusters of domain knowledge that students are formulating and accessing in order to accomplish the task. Similar to a semantic net, these nodes will have little organization initially

and serve more as general schema-like representations for the knowledge until more learning and practice impose an organizational structure on them.

To interpret the semantic content of the propositional unit requires some fundamental linguisitic interpretation. However, a detailed linguistic study of the questions generated is beyond the scope of this paper. I will focus on simple lexical and semantic interpretation and refer to the pragmatic level of discourse in relation to the context of the task. Each phrase will be decomposed in three steps into a representation as illustrated here:

Example question:

How do I erase?

1. Linguisitic Frame:

(<question particle><propositional unit>)

2. Analytic Frame:

(<question type><context><knowledge node>)

3. Interpretive Representation:

(<Procedural><Goal Space><Editing node>)

As an example, in the context of the task, the subject had considered a goal of editing whose procedure was unknown to the subject.

Now that I have presented the concept of pedagogical questions, their role in learning, and an interpretive model for decomposing the questions, I will present a brief overview of procedural learning in command languages.

COMMAND LANGUAGE LEARNING

Lotus 1-2-3

Lotus 1-2-3 is a command language for creating electronic spreadsheets which allows the user to input data in a two-dimensional grid space displayed on the computer screen. A variety of commands and functions are available for manipulating data. Commands are called using a menu system and executed after setting various parameters by pressing the 'Enter' key or carriage return. Users can perform sophisticated numerical calculations by formulating and executing Lotus specific functions.

Spreadsheets can be saved and stored in computer files, used to create graphs from selected data, printed as hardcopy, sorted and manipulated as a database, and even programmed to perform data manipulation in user-specified ways by the execution of Lotus 1-2-3 macro statements. The domain knowledge consists of a series of specific operators, syntax and procedures for accomplishing these tasks.

Because command languages are both used and learned on computer systems, the interaction of the device model for the computer system and the domain model for the command language knowledge the student employs during learning may play an important role in the acquisition process (Kieras & Bovair, 1984). To facilitate human-computer interaction in a learning situation, a common representation or model of the problem or task is desirable. However, in order to have a common representation, we must first identify the representation of the task in light of the user and the system. Command languages employ a command-execute cycle (Moran, 1981) in their application which differs somewhat from the program-run-execute cycle of traditional programming languages. This difference may impact on how the procedures are learned in command languages and the eventual mental model for the knowledge. In order to describe the mental model acquired during learning a skill such as a spreadsheet command language, we must first define the component parts of the domain. At minimum, the representation of initial and goal states, operators for performing in the domain, and the condition-rules required to complete tasks and obtain goals states must be identified. Once completed, we can begin to investigate the role these components take in the formulation of the mental model for the domain.

Early Learning: Transition to GOMS

The learning process can be studied using an incremental model to describe the knowledge representation at various stages during learning. However, the type and form of knowledge acquired and used at these various stages may require different representational models. The student's representation may or may not correspond to that required to accomplish the task (Kay & Black, 1984). This is particularly the case for novice learners. Card, Moran, and Newell (1984) propose a theoretical framework, GOMS (goals-operators-methods-selection), for organizing the hierarchical goal structure for complex cognitive skills. According to this theory, the cognitive structure for the skilled behavior consists of the four components in the model. However, the GOMS model is a theoretical construct that deals only with well-learned skills.

Along the continuum of learning, novices rely heavily on problem solving behavior for performing tasks (Card, Moran, & Newell, 1984) until an adequate database and structure for the knowledge is obtained. Novices begin learning by acquiring and building a declarative knowledge base of facts and features for the domain (Anderson, 1982, 1985). Because the structure and function of the knowledge are poorly understood at this early period in the learning process, novices may access prior knowledge structures of similar content areas to help themselves understand and process the information until a sufficient organization for the knowledge is established (Adelson, 1981; Anderson, 1982; Kay & Black; 1984). Continued learning refines and builds on the initial knowledge adding appropriate goals, operators, procedures, and rules for optimal functioning in the skill area. As learning continues, skill performance in the domain changes from problem solving behavior to more skilled performance reflecting instantiated proceduralizations for the domain. This change in behavior should be reflected in the changes in the representation of the student's mental model as well. Novice to expert differences (Adelson, 1981; Soloway, et al, 1981; Kay & Black, 198) provide further evidence for these

structural changes in knowledge representation as a function of learning coupled with practice. Kay and Black (1984) report that the student model will take on goal, state, and plan changes with learning that will allow for more expert performance as expertise develops. However, this model transition is poorly understood.

Acquisition of Procedural Skills

Learning involves three basic stages: encoding, where factual or declarative knowledge is stored in memory; proceduralization, where facts acquire function and are transformed into procedures; and composition, where procedures gain speed in execution with practice (Anderson, 1985). As learning progresses, the knowledge base for declarative knowledge increases. With little structure, immediate, 'on-line' interpretation of the information is required for understanding which places a burden on working memory capacity when large amounts of new information are being processed. Interpreting declarative knowledge is inefficient and can also introduce error as a function of retrieval from long term memory when dealing with a poorly structured body of knowledge. Search through a body of knowledge takes longer when organization and structure is lacking. Practice of the skill allows repetition of procedures and certain patterns and similarities may begin to emerge. With continued learning, refining, defining, and tuning the knowledge, adequate structure, organization, and proceduralizations are formed. Holyoak (1984) calls this process model construction. This model permits more efficient search in memory that results in better, more skilled performance.

Problem Solving Strategies

When students begin learning a new domain they have no structure for the knowledge and they employ general problem solving methods to find solutions to the problems they encounter. Newell (1980) calls these methods weak because at the very early stages of learning when the knowledge is largely unstructured, they provide little power for finding solutions. Artificial intelligence researchers have studied may of these weak problem solving methods in order to develop simulation models for the learning process (Newell, 1980; Neches, Langley, & Klahr, 1986). Heuristic search, means-end analysis, and operator subgoaling are but a few of these methods currently identified. Problem solving is a common learning strategy in the early phases of learning, however, this strategy can also occur for non-novices when the instruction lacks specific flow of control (Anderson, 1982) or when the task as problem space presents a problem to the person faced with accomplishing a given task (Newell, 1980). Indeed, even experts resort to problem solving when faced with a novel problem in a given domain.

Anzai and Simon (1979) propose a theory of learning by doing in which the learner acquires task appropriate problem solving strategies through the dynamic process of attempting and applying new strategies within a specific task environment. According to this theory, as the individual applies various weak-method problem solving strategies, a correct solution path can eventually be learned. A sequence of strategies that have proven successful in previous performances will be applied by the problem solver in a more rapid and assured manner in subsequent, similar problem spaces or task subgoals. An analysis of

the learning process, such as that reported by Anzai and Simon (1979) provides evidence of an emerging solution strategy based on prior performance within the task environment.

From this discussion one can easily understand that problem solving methods will be the predominantly exhibited behavior for novices learning new skills. Soloway (1986) proposes a general incremental problem solving model for learning programming languages. He contends that this is founded on the fact that expert programmers employ this strategy and that by encouraging novices to adopt the model, their learning rate should improve. Command language learning is similar to programming language learning, however, Anderson (1985) suggests that learning by induction appears to be a more useful strategy. His work suggests that the process of knowledge compilation will transform the weak problem solving methods into domain-specific productions for the skill. Perhaps an incremental problem solving model could provide this transformation to a GOMS model for learned skills if it provided for the compilation of procedures at various stages during learning. Their is no evidence, however, to support this claim.

Skilled Performance

An important factor for the success of the knowledge compilation process in transforming the weak methods into viable productions that lead to skilled performance is the formation of accurate goal structures for the knowledge. Goal structures are defined by the nature of the task and the procedures required to accomplish the goals. This factor is a critical instructional issue and education based on presenting these structures as a framework for the knowledge can help improve learning by making the goals more explicit. Only through learning and practice of the skill knowledge is an appropriate domain goal structure acquired. This goal hierarchy construct is a central component of the GOMS model.

Compiling and automatizing skill knowledge are discussed in detail elsewhere (Neves & Anderson, 1981, Newell & Rosenblum, 1981) and the reader is encouraged to review these articles for additional information on this topic. The point to be made is that all novice learners adopt problem solving strategies until the goal structure for the domain is learned. Through the learning process the transformation of the student's problem-solving model to one based on the GOMS framework occurs as the knowledge becomes proceduralized in service to the goals acquired for the domain. Thus, skill proceduralization in a well-defined, goal-oriented domain allows the student to perform more efficiently as function is added to the form of the knowledge.

With a basic understanding of pedagogical questions, an interpretation model, and procedural skill learning, we are now ready to proceed with a discussion of the functionality of questions in memory and how their interpretation can describe a student's knowledge state.

QUESTIONS AS PROBES IN MEMORY

The pedagogical question is articulated with a goal of obtaining a particular instruction or knowledge element to complete understanding of a given skill component. The goals of these questions will change as a function of the three interacting representations of the domain knowledge structure during learning (Newell & Simon, 1972): the student's developing internal representation, the external representation of the task environment, and the conceptual representation used for instruction during learning. As the student's representation for the knowledge evolves, changes in its organization will depend on which aspect of the domain goal structure is currently being learned and the relevant knowledge the student needs to know about for understanding a particular concept, procedure of goal. In this way, the student's interaction with the domain knowledge impacts on his developing representation during a particular instructional sequence. The student actively involved in accomplishing a particular task in a situated learning by doing paradigm will respond to the task environment as problem space and how it is perceived in developing and organizing knowledge in his or her current representation. In a similar manner, the current instructional sequence and which particular goals, procedures or operations are presented will affect what aspect of the knowledge is currently active. Thus, the top level goals of the questions asked will change depending on which level a student is currently interacting in with regard to the domain knowledge structure, the task space, and the instructional sequence.

A presupposition to this phenomenon of question asking is that the questioner has searched memory for information, found it was not available, and evaluated a requirement for asking a question to obtain what is needed for understanding or to perform some activity in the task environment. In order to understand how pedagogical questions function as probes in the memory system in a learning by doing paradigm, three components requisite to an inquiry memory search must be understood: question form, level of search, and search control strategies.

The type of question asked, in conjunction with its contextual meaning, will determine the conceptual 'form' of the question. (Norman (1979) in fact states that the proper form for the query is necessary before a search in memory can be performed. In order to further define the question form, one has to understand the nature of the domain knowledge that will be accessed by the inquiry memory probe. Neither Lehnert's nor Grasser's models, which dealt with text processing as the domain of interest, accounted for the three interacting representations of the domain of the knowledge structure when discussing memory search.

The form of the question asked will necessarily direct the query to one of these locations in memory in association with the knowledge node and the particular element accessed within a node. The question probe may solicit information that deals with specific operators and operations for accomplishing some goal, the methods with which to carry out a particular operation or procedure or even the initial problem solving strategies used as the correct methods are acquired. Questions may also seek knowledge that describes the concepts, features, properties, and selection rules for a particular knowledge element. The form will define the path of the query as it links itself to the knowledge node

of interest and leads up to where the appropriate answer should lie.

Question form in this model is interpreted by coupling the question type with the propositional context. For example, a feature specification question about a specific operator property will direct the question to structural information associated with the knowledge element probed within a particular node:

"How far can the pointer key move on the screen?"

Here the keyboard node is accessed and structural information about specific operational features is requested about a particular key. On the other hand, a procedural question about a particular operation will probe for functional information within a node:

"How can I center this title?"

Here the data entry node is accessed for procedural information about centering a title row. As learning continues, the form of the question should take on changes as a function of learning. As more information is encoded and stored in the knowledge nodes in the developing representation for the knowledge, the student will have more information on which to draw for asking questions. And so it follows that the organization of the representation will take on a more accurate structure as domain appropriate goals are learned. This will allow the student to articulate more precise questions and get the exact information that is needed. These changes in form will in turn affect the path the search takes in memory when accessing the knowledge representation as well as the level of the search.

The level of search in the memory system is also learning dependent. As the student learns, more information is acquired and a domain dependent organization for the knowledge structure takes form. The level of completeness for the structure will control the level of search when a question is formulated. Novices in any domain would not be expected to ask questions about skills or information they don't know about. Students might begin by asking general questions searching across the nodes in memory or accessing several nodes rather than focusing on the node associated with a particular item that may not yet be instantiated within the representation for the knowledge. Thus, at the early stages of learning, a breadth-first search of memory may be employed until an appropriate organization with a more complete knowledge structure associated with the student's internal representation is acquired. The novice student will attempt to locate in memory what it is he needs to know in formulating his query; so to for the more practiced student. This makes intuitive sense when we consider what is known about knowledge compilation, spreading activation, elaboration, and changes in the knowledge representation during learning (Anderson, 1982; Card, Moran & Newell, 1983; Kay & Black, 1984). Continued practice and learning in the domain will develop more complete structures in the representation and the level of search when questions are asked may take on a more directed, depth-first approach. Therefore, different question forms will search different levels of memory as a function of the completeness of the structure. This completeness of structure is in turn dependent on learning.

Other factors in the memory retrieval process may affect the level of search or even the search process in general. How memory is searched is a problem researchers continue to actively investigate and it is a process that is by no means yet completely understood. However, such factors as recency, decay, and forgetting may also play a role in the retrieval process (Neches, Langley, & Klahr, 1986). Although these factors are of paramount importance to memory search, they are not the focus of this paper. Nevertheless, as students begin learning, storing, organizing, and retrieving information in memory, their question formulation process may be affected by any one of these factors.

Finally, we need to consider the search control mechanisms that apply as questioner's probe memory in articulating their questions. Question function is defined by relating the question form with the temporal sequence of task space interactions (goal-action-state) in a particular learning or practice segment. This temporal/sequential component will serve as a control mechinism for searching the knowledge structure. Search control can be defined by two factors affecting question function: system response or feedback, and the instructional sequence. As search control is manipulated by performance feedback and instruction (also a form of feedback), question function will shift and ultimately affect the strategies used to probe memory.

Performance feedback will direct the questioner toward a certain path in memory dependent on the active problem space in which he is interacting by providing the student with information to evaluate and match with what is currently in the knowledge structure as he formulates a question (Collins & Brown, 1986). In much the same way, the instructional sequence will provide the student with situations to evaluate with what is currently stored in memory. The particular time within an instructional sequence that a question is posed will define search control based on the completeness of the knowledge structure, what is known about the goals, operators, methods, and selection rules, what needs yet to be learned, and the strength of association for the knowledge or how well it is learned.

As search control is altered by these two types of feedback, so to is the function for the question. Questions may serve a simple information retrieval function, to elucidate information about a causal relationship, specify selection rules for a particular operation, or assess an hypothesis about some task operator. In order to understand more fully how these functions affect search control, the interpretation model must define the mechanism for connecting the question probe to the knowledge node accessed with the student's current knowledge representation.

In a complete question system there is the query, the knowledge base or structure accessed, and the answer. Here I am only concerned with interpreting questions in order to describe the questioner's knowledge state. However, to do so, I must address the entire system to some extent. In order to describe the questioner's knowledge representation through interpretation of the questions asked, the context of the conceptual domain knowledge structure will be used to define the representation. This structure and the question types will be used to define the input relations connecting the query to the answer.

Figure 1 depicts a graphical notation for the types of probes in this model. The input links, representing a question's conceptual category, connect the question probe to the knowledge nodes accessed. Their relations are defined using Lehnerts' interpretation rules. The context classification indicates a functional distinction that further defines the problem space for each probe as it traverses the knowledge structure. Thus a probe continues its search in either a goal, action, or state problem space associated with the knowledge nodes accessed in memory. The output links are pointers to the desired information (the answer). Output relations define functional, structural or process components associated with the requested information. These relationships might include the constraints or implementation process associated with legal operators; the results of state transformations or confirmation of a fact. The articulated question will thus probe memory by pointing to a particular knowledge node through the function of the question form. What the questioner needs to locate, but does not yet have stored in memory (or cannot locate because of retrieval processing constraints imposed by the instructional sequence or task requirements), is the output link, its relational definition, and the associated information.

IMPLICATIONS FOR KNOWLEDGE REPRESENTATION

How is it that a question analysis methodology can be used to derive a representation for the knowledge? A complete description of the kinds of questions that comprise the question set that is part of the system for procedural learning is a first step toward understanding the role of pedagogical questions in the development of a knowledge representation for the domain. Lehnert (1978) maintains that in order to answer questions, the answerer, whether machine or human, must retain the model of the questioner's knowledge state. Evaluation of the kinds of questions asked in a learning by doing paradigm following a tutorial session should provide information that is descriptive of this knowledge state model. Changes in the kinds of questions asked about the operators and methods a learner is applying to solve the task problem should reflect the changes in his/her knowledge state as the information sought is placed in the student's domain model. In addition to interpreting question types, an analysis of the temporal placement of the question in the protocols collected should reflect the nature of the search control during the task as different problem solving methods are applied to the problem. Questions asked at the boundaries of strategy shifts as the student learns the appropriate solution strategy for obtaining a task goal may provide information for understanding how and when this strategy shift process occurs.

I believe that if the goal hierarchy for the domain knowledge is well defined as is the case for learned procedural skills, the interpretations of the questions will point to specific knowledge nodes in the domain that possess the

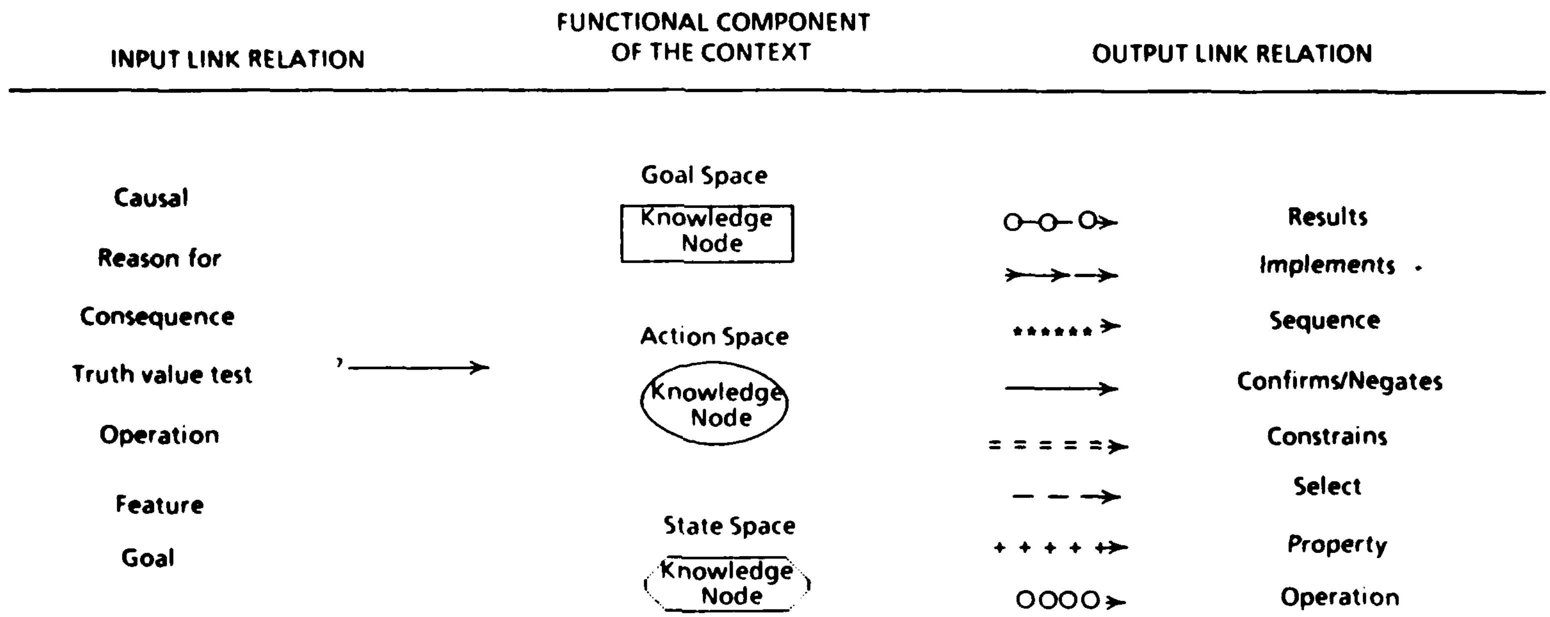

Figure 1 Links and Functional Representation for the Question Probes

information the questioner is seeking in relation to how the knowledge is being acquired. Further, the sequence of the questions in relation to the dynamic problem space for the task will provide additional interpretive information for the knowledge state changes as a students' internal representation develops. The success of the question interpretation method relies on the contextual constraint of the domain and the interaction of the student within a situated learning by doing instructional environment. By analyzing the questions in a well-defined goal-based hierarchical context, one can more accurately interpret the utterances and be more specific in tracing the paths the query takes through the knowledge structure. I assume a hypothetical organization for the domain knowledge based on concurrent research (Gray, Mutter, Swartz, & Psotka, 1986) that is attempting to define novice to expert differences in command language learning as shown in Figure 2. This structure, apart from the editing goals, was used as part of the instruction in the experiment.

An analysis of the kinds of questions students generate while learning a skill on a computer may provide information about a specific knowledge state that can be mapped unto the developing representation for the knowledge as students learn the concepts, procedures, and skills of the domain. In the learning process for procedural skills such as command languages, student questions should indicate what particular kinds of declarative information, operators, and goals they need in order to perform a given task and when the information is needed. This information should indicate the mechanisms by which students acquire and structure the newly learned knowledge.

The following section presents some preliminary data from a question asking study during a procedural skill learning task.

EXPERIMENT

An experiment was conducted in order to collect baseline question asking data in a procedural skill learning task. Novices were given minimal tutorial training and practice prior to the experiment and then encouraged to solve the task problems presented to them in a learning by doing paradigm. The proposed question interpretation model was used to analyze the data from verbal protocols. Results and discussion are presented below.

METHODS

Subjects. Six undergraduate college students at the Catholic University of America participated in this study. This experiment was part of their psychology course requirement.

Materials. The command language under investigation was LOTUS 1-2-3. The task involved constructing four simple spreadsheet problems on a computer. Cognitive task analysis for the spreadsheets was undertaken to ensure that all four problems were of similar difficulty and to identify the goal-action structure for the task. Order of presentation of the spreadsheets was randomized using a latin square design. (See Appendix 1)

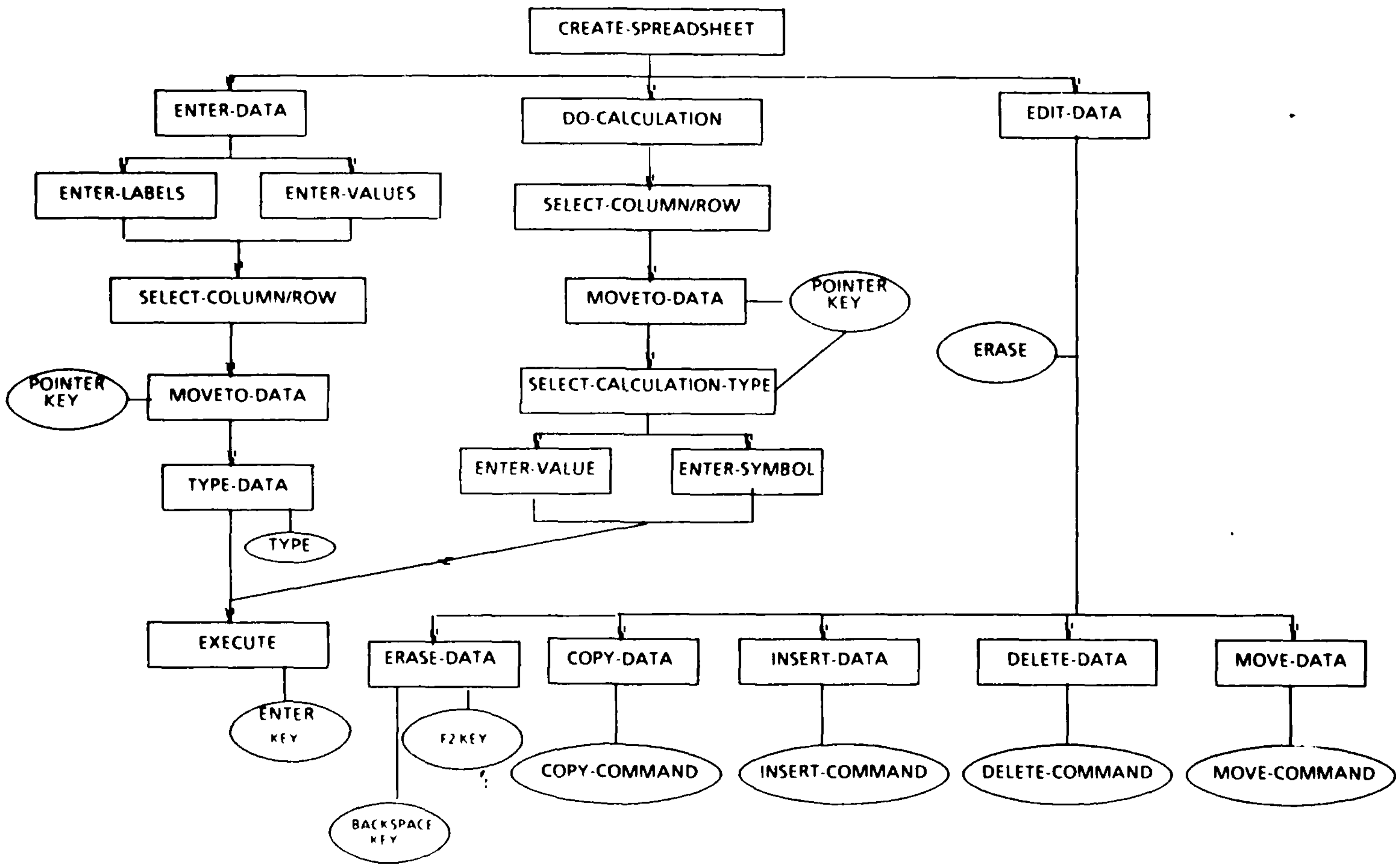

Figure 2. Simplified Conceptual Goal Structure for Instruction in LOTUS 1-2-3

Note: Boxes are task goals
Ovals are operators
Links are: → do-next
— get-operator

Procedure. The experiment was a within-subjects design measuring number of questions asked per spreadsheet. The trial consisted of four spreadsheet reconstruction tasks. The trial was done on an IBM-XT equipped with a hard disk drive. Subjects were administered a computer skill survey after informed consent was obtained. All sessions were video-taped and audio-recorded using VHS video recorder equipment. The video recorder was aimed on the computer screen and positioned unobtrusively behind the subject. A keystroke and timing program were used to capture keyboard behavior and time on task. Each subject was given fifteen minutes of instruction in a socratic-like tutoring session on how to move around the spreadsheet, enter data, and create simple calculations in LOTUS 1-2-3. Five minutes of practice with sample exercises was conducted before the study began. The sample exercises were left as guides during the experiment. No constraints were made on completing the task. Preliminary exercises indicated that one hour would be enough time for naive learners to accomplish the task. The experimenter was to stop the subject only if he/she remained in an error state for more than five minutes. Subjects were instructed to reconstruct the four spreadsheets on the computer. They would be helped to save the spreadsheet and begin the next one in the trial. Subjects were instructed to think aloud as they solved these problems and to ask questions aloud when they weren't sure of what to do or how to proceed. Although the questions would not be answered until after the session, subjects were encouraged to ask questions anyway and then try to reconstruct the spreadsheets as best as they could. After the session, the experimenter would provide them with any information about LOTUS 1-2-3 that they wanted to know.

RESULTS

One of the principal goals of this preliminary study was to begin defining the pedagogical question set for command language learning. The results are presented here with only nonparametric analyses of the questions and any relationships between them and the knowledge sought by the query. Once a basic question set is defined and interpreted, further more rigorous analyses of question generation will be performed in subsequent research.

Protocols were transcribed with questions placed on a separate line, but kept within the text. There was a great deal of variation in the form and content of the utterances and using the context of the protocols was essential for interpreting questions in cases of ambiguous references, ellipsis, or anaphora. Questions were analyzed according to the interpretation methodology presented above. Individual differences were noted in the subjects natural tendency to speak. Some were simply more talkative than others even though a practice session preceded the experiment to render the talk-aloud method more natural. Also, subjects were requested to ask questions and this may have forced an unnatural quality into the experiment that might not be truly reflective of a typical instructional setting where students naturally ask questions. No attempt to adjust this difference was made in this pilot study, however, plans for future research will do so.

Subjects provided a total of 166 questions. Redundant questions were subtracted out before any further analysis began leaving a total of 130 questions, an average of 21.7 questions per subject. Figure 3 indicates that subjects asked fewer questions as time went on. However, this overall trend was not

evident for all types of questions. This simple factor represents an overall tendency for asking questions during learning. As novices in the domain, one expects a lot of questions at the initial stages of learning and this finding appears to validate that fact.

Seven conceptual categories emerged from the analysis of the questions: procedural, goal orientation, causal antecedent, causal consequent, conceptual completion, feature specification, and verification. These seven conceptual categories times the three problem space context categories (goal, action, state) yielded a rather large 21 category matrix of question types. Table 1 illustrates the categorical breakdown for the questions. Three categories with the highest frequency accounted for more than 70% of the questions asked during the trial: procedural questions (29%), goal orientation questions (22%), and causal antecedent questions (22%). This finding is not too surprising as one would expect these sorts of questions in a highly procedural domain such as LOTUS 1-2-3.

From the total number of questions asked (130), three knowledge node types accounted for 64% of the questions asked, data entry (35%), editing (15%), and calculations (14%). To determine whether there was any relationship between the question types and the information the subjects were seeking in their internal representations for the knowledge in order to perform the task, I conducted a chi-square test on the data matrix for the most frequently occurring question types (procedural, goal, causal antecedent) and knowledge nodes (data entry, editing, calculation). Table 2 presents total frequencies for each category in the matrix and chi-square values for two identified relationships. Since several of the individual cells in the matrix had frequencies less than five rendering any analysis meaningless, the test was conducted on only one row and one column of data. The results revealed a significant relationship between procedural questions and the three knowledge nodes, $X^2(2,N=6) = 7.95, p<.05$. The relationship between the data entry knowledge element and the three question types approached significance, $X^2(2,N=6) = 5.38, p<.05$. Although this particular test cannot specify more specific associations between the data, it is none the less interesting to note that procedural knowledge is most often asked about both in question type and knowledge node.

The number of error-generated subgoals for the spreadsheets was calculated by subtracting the total number of task subgoals identified from the total number of subgoals each subject generated. The differences in total subgoals per spreadsheet were $t(6)=2.03, p<.05$, for spreadsheet A; $t(6)=1.32, p<.05$, for spreadsheet B; $t(6)=0.90$, $p<.05$, for spreadsheet C; and $(6)=0.73, p<.05$, for spreadsheet D. None of these tests were significant due to the small sample size. However, the considerable variation of subgoal number per spreadsheet is indicative of the novice problem solving methods employed by the subjects.

Total time on task was measured for each spreadsheet reconstructed and the mean time derived across subjects to reflect the learning curve for the task. Although these subjects were novice learners, the theory of learning by doing (Anzai & Simon, 1979) supports the notion of skill acquisition through practice

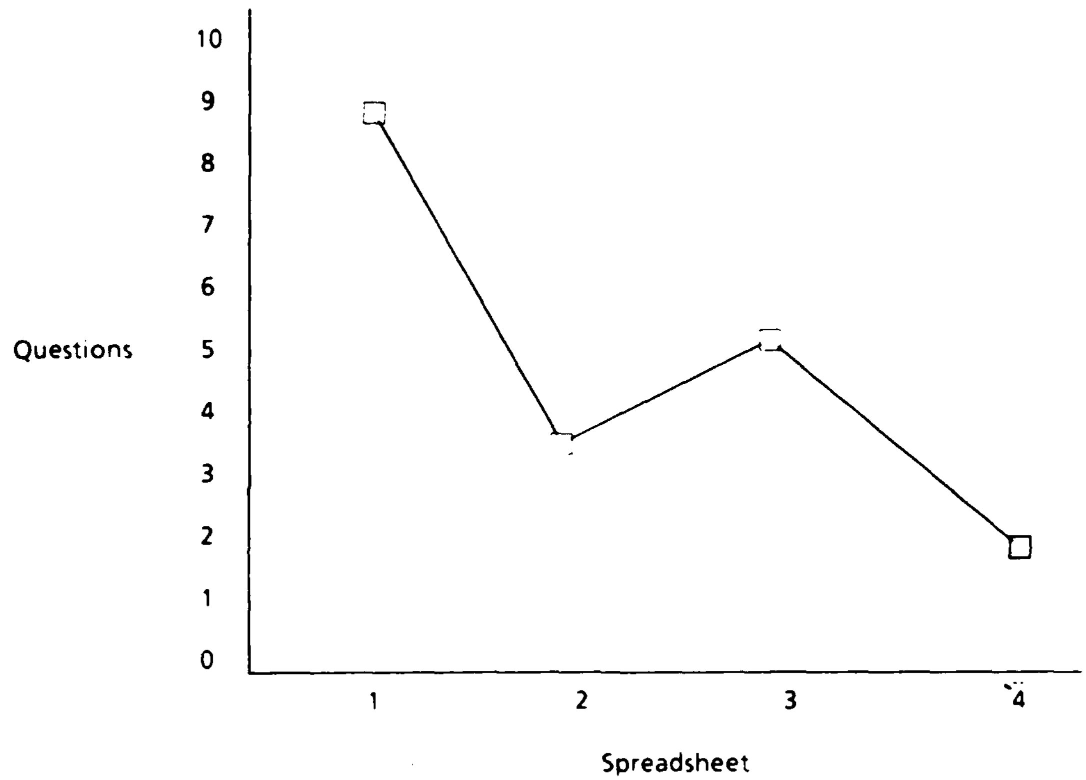

Figure 3 Mean Number of Questions Asked

Table 1. Numerical Breakdown of Questions by Conceptual Category and Context Classification

Conceptual Category	Context Classification												
Task	1			2			3			4			
	G	A	S	G	A	S	G	A	S	G	A	S	Total
Procedural	6	6	1	3	3	2	8	3	--	4	2	0	38
Goal Orientation	7	3	1	8	--	--	3	--	1	2	--	3	28
Causal Antecedent	1	8	4	2	3	0	1	7	--	--	1	1	28
Causal Consequent	--	1	3	--	2	--	3	--	1	1	--	--	11
Conceptual Completion	--	--	5	1	--	1	--	--	1	--	--	1	9
Feature Specification	--	--	2	--	--	2	--	--	--	--	--	--	4
Verification	3	1	2	--	1	2	2	1	--	--	--	--	12
Total	17	19	18	14	9	7	16	12	2	7	4	5	130

G = Goal Space
A = Action Space
S = State Space

Table 2. Relationship Between Question Probes and Knowledge Nodes in the Internal Representation

Question Category	Knowledge Node: Data Entry	Edit	Calculation	Total
Procedural	11	15	5	31
Goal	10	1	3	14
Causal Antecedent	13	0	2	15
Total	34	16	10	60

$\chi^2 = 7.95, p < .05$ (procedural row)

$\chi^2 = 5.38, p < .05$ (data entry column)

while solving a problem. Because four spreadsheet reconstruction tasks made up a trial, I had anticipated at least a modest learning curve. Results using mean times are presented in Figure 4. Although the curve is not dramatic, it does offer some support for general learning during the task. However, the problem of error-generated subgoals was not accounted for in this global measure. Admittedly, in this initial study subjects were not provided with any tutorial help or responses to their questions and this most probably contributed to the limited overall learning. Also, the domain involves more complex cognitive skills and problem spaces than in the Tower of Hanoi, for example, which may also factor into the overall learning curve for the task.

DISCUSSION

Question Interpretation

Novice learners are just beginning to acquire the knowledge necessary to perform the target skill. They tend to be uncertain about what procedures to use and which solution strategies will work best. Therefore, novices in general are more inclined to ask questions about these skill components (Chi & Glaser, 1980). Any reduction in question asking over time may suggest that novices are learning the correct procedures and solution strategies, however, I cannot make this claim based on the data here. The results do tend to confirm Chi and Glaser's claim for general high frequency question asking by novices.

Procedural Questions. These question types were the most frequently asked question type in this experiment. Procedural questions were most often asked about when considering a goal or action that subjects were attempting to solve in the task environment. For example:

1. "I don't know how to do it."

   (<Procedural><Action Space><Data Entry Node>)

2. "I don't know how to do those lines"

   (<Procedural><Action Space><Data Entry Node>)

3. "I can't figure out how to move the mover where I want"

   (<Procedural><Goal Space><Calculation Node>)

4. "I'd like to figure out how to move one space."

   (<Procedural><Goal Space><Screen Movement Node>)

The first two questions are seeking appropriate operators to accomplish the procedure under consideration. In question one the subject had already selected and begun work on a task subgoal, entering label data into the spreadsheet, and doesn't know how to set the CAP LOCKS key for capital letters. In

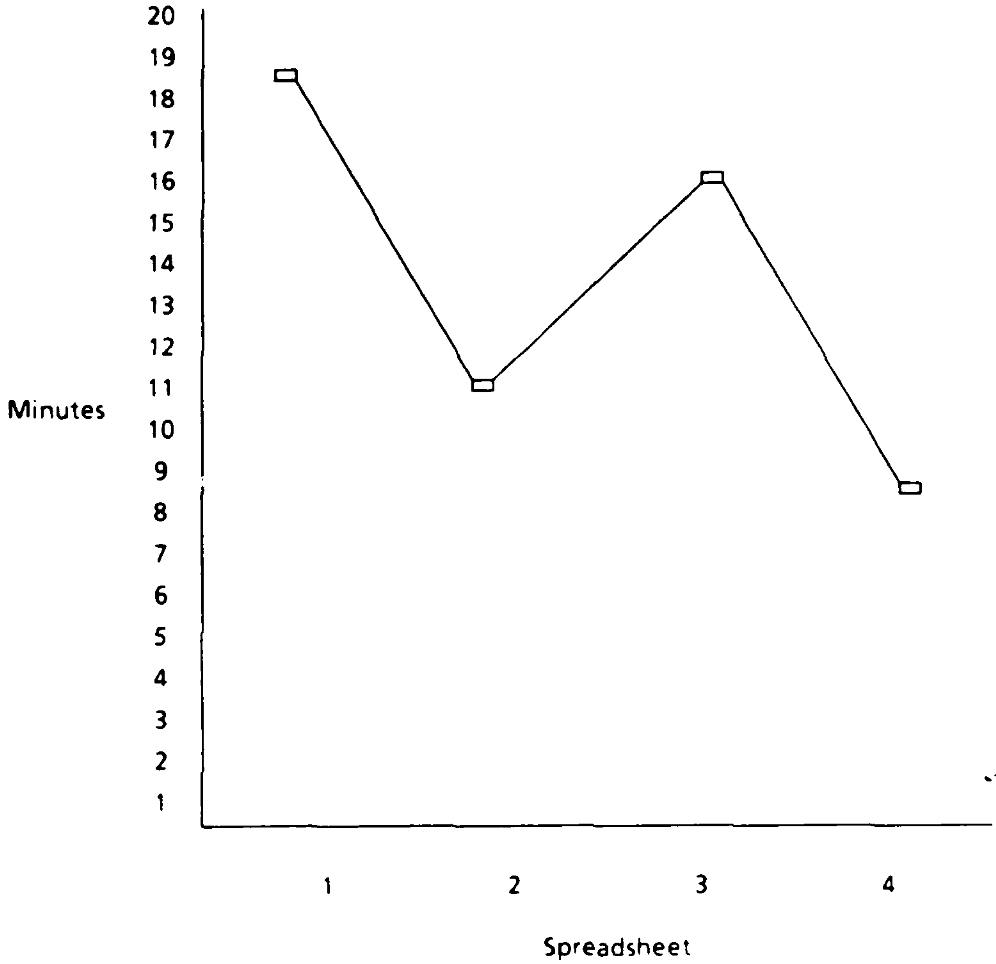

Figure 4. Mean Time on Task

question two, the subject asks the question after she has applied an operator that has proved unsuccessful for obtaining the desired subgoal state. As a result, her question refers to a procedure in an action space she is concerned about. Compare these with the next two questions that are posed prior to considering other subgoals and consequently other contextual spaces. The verbs used and the sequence of events in the protocol were guides for discriminating between space contexts. In questions three and four, the verb 'move' is used that can refer to an operator or action. However, 'when' the question is asked further defines the context classification. These questions were asked before the subject began another subgoal, so the temporal quality of a question can change the meaning. The results indicate that all questions asked before a subgoal is attempted refer to goals. When questions were asked after a subgoal has been approached and selected, they generally referred to actions. Procedural questions tended to increase slightly over the tasks in the trial which may be indicative of the importance of knowing about correct operators for specific actions and goals in the early stages of procedural learning.

Goal Questions. The second most frequent kind of question asked were goal orientation questions. These questions were asked when subjects were considering a particular task subgoal and on occasion to evaluate some system state goal they encountered. According to Lehnert, goal questions are typified by their inference of asking for a 'reason for' or 'possibility of' a motive or goal behind a particular action. Her analytic approach to question interpretation was within the domain of text processing, and this renders a specific meaning to the goal orientation conceptualization category she used. In procedural skill acquisition, however, the goals and subgoals are much more clearly defined within the task environment. The interpretation here was facilitated by the cognitive task analysis of the problem space. Each spreadsheet was broken down into the number of subgoals required to complete the reconstruction task. The goal decomposition began with 1) global task goal (reconstruct spreadsheet), 2) task subgoals (the number of columns of data on a spreadsheet), and 3) column subgoals (the individual rows of data making up a column). Hence, any question asked as the subjects considered or referred to one of these subgoals during the experiment was interpreted as a goal question. Questions about all three of these goal categories were asked. Goal orientation questions were most frequently asked in the first task trial and dropped off markedly during the rest of the tasks in the trial. For example:

1. "I wonder if I can 'bump' (erase) that?

   (<Goal Orientation><Goal Space><Editing Node>)
2. "What can I do?"

   (<Goal Orientation><Goal Space><Spreadsheet Task Node>)

3. "Now where am I"

   (< Goal Orientation><State Space><Spreadsheet Task Node>)

In question one the subject is considering an editing subgoal and in number two a simple task subgoal is being considered. Here, the subject paused in reconstructing the spreadsheet and considered his next subgoal decision. Question three refers to goal orientation in the system state space. Here the subject paused during the task and scanned the spreadsheet for the next logical subgoal to consider.

It might be argued that both of these last questions are merely rhetorical, but further analysis of the pragmatics of these utterances within the context of the task reveals their intentional inferences. Question two provides an indication that the student is unsure of which subgoal to logically attempt next within the problem space. Novices tend to chunk information within a task differently than experts do (Chi & Glaser, 1980). Skilled performers know the goal structure inherent in the problem space of the task environment and therefore can proceed rapidly in the selection and execution of task subgoals. This novice subject seemed perplexed by the task at this point and was seeking guidance through a question in selecting the next subgoal.

Question three carries an additional component of spatial orientation ('where') which could be indicative of either a memory or a perceptual problem in scanning the spreadsheet for the next subgoal. It is indeed difficult to define the inference denoted here, however, it seems reasonable that novices might 'lose track' of what subgoal they should consider next since the task goal structure is not well-formed at this stage of learning. This 'losing track of' phenomenon could be a combination of short term memory overload and/or perceptual complexity effects on spatial orientation for an unfamiliar task.

<u>Causal Antecedent Questions</u>. The third kind of question, causal antecedent questions, were asked as frequently as were goals questions. This particular question category is interesting because of its implications for hypothesis testing and reasoning about the newly acquired skills. Students asking causal antecedent questions are asking about causal relationships between certain task states, operators, procedures, goals, and the like. Questions generating hypotheses suggest that the learner is beginning to create some sort of structure for the knowledge (Miyake & Norman, 1979). As the subjects were learning how to proceed in the task, what operators to use, the correct sequence of actions to follow and so on, they presumably began to generate and test hypotheses concerning these aspects of the skill knowledge. When the system response was not what they had anticipated based on their hypothesis, subjects were inclined to ask causal antecedent questions.

For example, in the following dialogue, one subject was trying to understand how pointer keys work to move around the worksheet space on the computer.

1. "Do these things here (pointer keys) move to this section?"

   (<Verification><Action Space><Screen Movement Node>)

2. "Why did this move over so many spaces?"
   (<Causal Antecedent><State Space><Screen Movement Node>)

The subject is attempting to understand a basic concept of how pointer keys function. Her first verification question suggests that she already thinks the keys she is referring to perform the operation in question. As a novice, she seeks confirmation of her hypothesis through a simple verification question. Then she proceeds to apply the operator to test its function, but does not end up in the anticipated subgoal state. Thus, question two seeks causal information to explain the current unexpected state change. All subjects were given instruction and practice on pointer keys and screen movement, however, holding down a particular pointer key continuously causes rapid scrolling in the direction of the pointer. More controlled movement occurs when the key is depressed using rapid, serial taps. This distinction in how the operator works is an important, although very basic one. The second question suggests that the subject had not yet learned this functional quality in pointer key use. In another example,

3. "How come they didn't capitalize?"

(<Causal Antecedent><State Space><Data Entry Node>)

a subject intended to set the CAPS LOCK key, but hit a neighboring key instead. In evaluating the system state transformation, he asks for the cause of the response. Certainly the subject expected capitalization and doesn't understand why this didn't happen. Of course, he didn't know the reason was because of his own error. Nevertheless, this type of question is useful in illustrating how he is thinking about the task. In the protocol he tries the action again and then reasons that he must not have had the CAP LOCKS key depressed earlier.

Infrequent Question Types. The remainder of the question category types accounted for only 31% of the total questions asked and thus did not appear to be too useful to students for acquiring information during this level of the learning task. Verification questions test the truth of a statement; they require a yes-no response. Novices are often unsure of their actions and how to proceed in solving a problem, hence their questions may simply seek verification of some fact or procedure a student is considering. It would appear that this type of question might rise in frequency as more experience is gained in the early stages of learning, but then asymptote when a specific level of learning is achieved. When students become more confident with the skill knowledge, they should no longer seek verification through this type of question. While these questions were not overly frequent in this experiment (12 out of 130) when compared to other more frequent question types, they did virtually drop off in the last task of the trial. This type of extinction may indicate that at a certain point in learning they are no longer required for confirming knowledge. This question type was the most difficult to interpret in the pragmatic sense of the utterances. In a few cases, although on the surface the question appeared to be one of verification, a specific goal or procedure category was the more appropriate interpretation. Much as the intent of a questioner asking "Do you have the time?" is really interpreted as "What time is it?" rather than a yes-no verification of the fact, questions in the protocols such as "Is there a way to cancel?" are really asking about the correct operator and are interpreted to mean "How do I cancel?", a procedural question about an editing goal rather than simple verification. This particu-

lar interpretation classification was only done if the context of the protocol and keystroke behavior made clear a more specific intention for the question. Further research is needed in order to test the notion of verification question use in early learning stages.

The low number of concept completion questions is surprising (11 of the 130 total) since I had expected novice learners to ask many of questions of this type. Concept completion questions are like 'fill-in-the-blank' questions. Perhaps in later learning this question type will appear more frequently as partially learned concepts require further information for understanding and refinement.

Feature specification questions refer to queries soliciting property or attribute information about a given entity. This category was the most infrequent of all. One might think that because novices are building up their declarative knowledge base for the domain, that they would be interested in learning about specific features of task entities. Yet at these early stages of learning, the novice may lack the required knowledge to fine tune concepts through this type of question. I suspect that the feature specification question occurs in later learning stages along with concept completion questions to build on what is already acquired when the learner has a basic knowledge structure intact and is in the process of refining and structuring the knowledge into a more meaningful representation.

Knowledge Nodes: Conceptual Building Blocks in the Problem Space

In describing the development of a subject's internal representation for the task, we must consider two factors: system feedback as a result of his performance in a given problem situation (Newell & Simon, 1972) and the instruction received about task goals, legal rules, and concepts that apply to the situation. The process by which one develops an internal representation can include one's internal thinking responses as the stimuli and perceived problems are dealt with (Newell, 1980; Newell & Simon, 1972). Articulated knowledge about a particular problem in the task environment can cause this knowledge to become available for solving and reasoning about the problem (Collins & Brown, 1986).

The knowledge nodes that subjects articulated through their questions and verbal protocol statements provide evidence that they are encoding, reasoning about, and accessing these areas in the domain as they begin to build their internal representation for the problem space. Learning by doing promotes individualized exploration in this space within certain task constraints. The particular knowledge nodes accessed through articulated questions identify different kinds of knowledge that subjects dealt with during the task within this learning paradigm. Figure 5 illustrates how these question probes might function in the early stages of learning as students build a representation for the knowledge.

Nine knowledge nodes emerged from the questions. These elements were classified according to concept nodes that reflect the highest general type of knowledge in the problem space. The knowledge nodes identified included: 1) data type = this conceptual node includes declarative information sought about

the types of data specific to LOTUS 1-2-3. For example, label (alphanumeric), value (numeric), and formula or function (calculation) information. 2) data entry = this conceptual node includes procedural, operator, and methods information needed to enter data into the spreadsheet. 3) editing = this conceptual node includes procedural, operator, and methods information about editing data in the spreadsheet. 4) spreadsheet task = this conceptual node refers specific information sought about the task goal. 5) worksheet features = this conceptual node refers to declarative information about display features on the screen and worksheet parameters (rows, columns, cell addresses). 6) system features = this conceptual node refers to information sought about computer system behavior. 7) screen movement = this conceptual node refers to both declarative and procedural information involved with moving around the worksheet space. 8) calculations = this conceptual node includes all information involved with creating and executing calculations on numeric data. 9) keyboard = this conceptual node refers to declarative information about key type and certain specific key functions.

The kinds of knowledge asked about reflects the nature of the developing internal knowledge representation and what the student regards as necessary for accomplishing the task goals. Here the instructional feedback was withheld during the experimental task and only system feedback affected their performance and subsequently the form and function of the questions. However, in classifying the different kinds of knowledge utilized as subjects performed the tasks, it appears that questions probed different knowledge structures: either domain or device knowledge, and within domain knowledge, either structural or procedural knowledge.

Domain Knowledge		Device Knowledge
Structural	Procedural	
Data Type	Data Entry	System Features
Keyboard	Editing	Keyboard
Screen Movement	Screen Movement	Screen Movement
Spreadsheet Task		

It appears that some of the knowledge nodes may share information that makes up each of the representations for the knowledge.

Subjects were provided instruction in the domain knowledge based on a conceptual representation shown in part in Figure 2. Certainly data entry and calculations were two concepts presented to the subjects as part of their raining. Although subjects were not instructed in editing knowledge, they did formulate questions that accessed this node. For example, the high proportion of questions asked about editing seems to be a function of errors generated in the task, a phenomenon quite natural to problem solving behavior with little

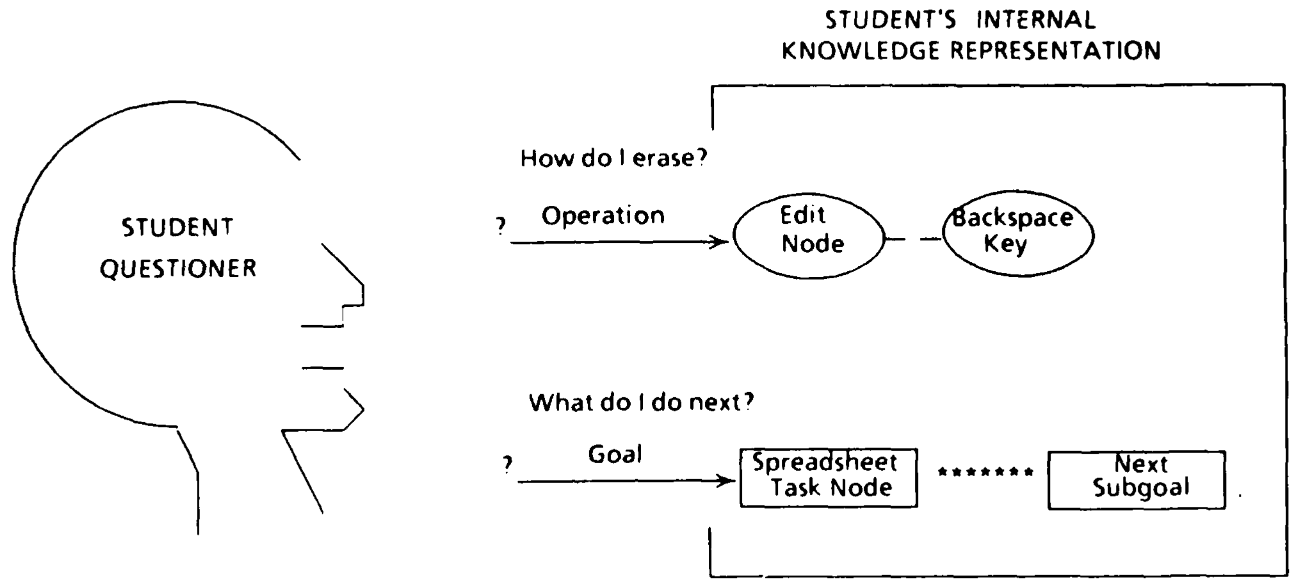

Figure 5 Symbolic Representation of a Questioner Probing Memory During Learning

feedback and control other than system response. The reader is reminded that the instruction for this experiment was confined to simple data types, data entry procedures, screen movement procedures, and calculation formation and execution. No instruction occurred during the experimental task. No instruction on the use of LOTUS commands was provided, and given the nature of the reconstruction task, subjects would have no occasion to ask questions specific to command concepts unless this aspect of the domain was discovered through application of random key presses.

Miyake and Norman (1979) stated that the number of concepts the learners asked about implies some measure of association between the student and the instructional material. Asking about a particular concept implies that the questioner knows what is necessary for more complete understanding of the concept. Data entry questions represented the most frequent knowledge element asked about. Twenty-five percent of the questions generated about data entry knowledge were procedural, goal or causal antecedent in question type. This particular knowledge node involves the most basic level procedure in the domain (See the TYPE-ENTER METHOD, P. 33). It is the first procedure acquired in the learning process and essential for task completion. Data entry behavior cannot be avoided in the task environment. The proportionately high number of goal questions for data entry knowledge is indicative of novice behavior. In early learning, even the most fundamental task goals and subgoals are not yet instantiated, hence more of this type question is asked. It also follows that a high number of procedural questions about data entry knowledge are asked to clarify what particular operators are required for data entry in various situations.

Editing knowledge was the second category most frequently asked about. While this finding may appear interesting at first glance, in this study it only reflects the subjects' attempts to correct the many errors they encountered during the trial. The reader is reminded that none of the questions were answered and that subjects had to revert to problem solving strategies to attempt a solution as best they could. Since no instruction was given about editing commands, one would expect a high number of this type of question as subjects expressed a desire to locate the operators and procedures to accomplish an editing subgoal. However, in a learning environment with instructional feedback from either a computer tutor or teacher (ie: answers to the questions asked), the need to ask about editing knowledge may be somewhat lower than was observed here. Further research in this area is needed for validating this claim. Nevertheless, these results indicate the importance for teaching editing commands and operations fairly early in the curriculum. The novice, who will be making a high number of errors initially, needs to have an understanding of the procedures and operators necessary to correct these errors in the early stages of learning. Editing knowledge, although not a primary instructional objective in command language learning, can prove useful for error-prone novices.

Calculation knowledge was asked about almost as frequently as was editing. This knowledge element was more task specific since each spreadsheet task within the trial had at least one calculation as a subgoal. This particular subgoal was more advanced than the others, for the most part basic data entry

subgoals, and required more cognitive effort from the subjects. Formulating calculations requires that the appropriate row or column of data is identified, the arithmatic operation decided upon, and the appropriate LOTUS 1-2-3 operator symbol selected to perform the desired calculation. Two forms of calculations, formulas or functions, are available in LOTUS 1-2-3 and were presented to the subjects during their training. Selection of one type of calculation over another presupposses the decision of what kind of calculation is needed in a particular situation. Often, either calculation method is possible and the student must decide which one to use. Most of the questions asked about the goals and procedures involving these calculations. The goal questions offer evidence for this calculation type decision subjects were faced with. As they gain more experience within the domain, this type of goal question should diminish in frequency.

Protocol Analysis: Problem Solving Strategies Observed

Protocols were analyzed in order to identify the most common problem-solving methods the subjects employed. Three strategies emerged and the protocol statements were grouped into one of the categories: 1) means-end analysis, 2) generate and test/operator subgoaling, and 3)'repeated successful' strategy. Further discussion of these strategies is available in other sources (Newell, 1980; Neches, Langley, & Klahr, 1986). The third strategy is named by the author and will be explained below.

A problem solver using a means-end strategy involves movement in a forward direction as operators are selected and applied to move the problem solver from the initial state to the goal state. When a means-end strategy proves unsuccessful, the problem solver may choose to apply other known operators or to experiment in an attempt to discover the correct operators required for achieving a particular subgoal state. This sequence of generate and test and/or operator-subgoaling does not necessarily move forward, but moves can involve both a forward-backward, backward-forward-backward direction as different operators are applied or new subgoals generated in which the operator of interest will apply. Application of a 'repeated successful' strategy implies that the problem solver has located a strategy that has been found successful for a particular class of subgoals. Sweller and Levine (1982) call 'repeated successful' strategies 'history-cued' since it implies that the problem solver is remembering a strategy based on the individual's performance history. This remembering was observed in this study, however, Sweller and Levine are talking about a strategy that involves considerably more learning than was the case here. Certainly with more experience in the task, I would expect the 'repeated successful' strategy to stabilize and shift into one that is truly history-cued.

Problems can emerge within the problem space as a function of the interaction between the task goals and a subject's perceived structure of the environment (Newell, 1980; Holyoak, 1984). Weak problem solving methods will be applied to these problems, declaratively organized in a novice's representation prior to the compilation process, to help interpret their implications for performance (Anderson, 1985). It was clear that the first logical strategy employed by all subjects was means-end analysis by selecting a goal state from the spreadsheet and attempting to reach that state by applying known operators.

There is considerable evidence in the literature to support a novice's use of this strategy when faced with a new problem (Simon & Reed, 1976; Newell, 1980; Neches, Langley, & Klahr, 1986). When a wrong operator was applied and the goal state not attained, the strategy generally reverted to a sequence of generate and test and operator-subgoaling strategies with the subjects selecting other operators or methods for accomplishing the subgoal. If a solution was eventually obtained using one of these strategies, the next similar subgoal the subject attempted applied the same strategy based on the previous solution success. When a solution was not found through a generate and test strategy, operator subgoaling was then used to find a state in which a particular operator would work. If still unsuccessful, the subject would either abandon the subgoal or after five minutes, the expiration would tell the subject to go on. When the means-end analysis was successful and a succession of similar subgoals remained, for example, entering a column of labels, the strategy became more rapidly applied to each successive subgoal. The term 'repeated-successful' is awkward, but conveys the meaning behind this strategy. The student has found a successful solution and uses it repeatedly. Evidence of this type of behavior can be one indicator of learning as search control time reduces for a particular subgoal class (Neches, Langley, & Klahr, 1986) using this strategy.

Newell (1980) calls this 'repeated-successful' strategy 'planning' to imply an abstraction from a successful means-end analysis, however, this terminology doesn't seem quite appropriate at these very early stages of learning. Subjects did show rudimentary planning, however, since the domain knowledge was so impoverished in this experiment, I would hesitate using Newell's term for this strategy type. Certainly all subjects showed evidence of planning as they attempted different solution strategies, but their 'plans' were not very stable over the trial.

Learning: Questions and Strategy Shifts

Indicators of learning include composition of procedures (Anderson, 1985), reduction of search time for a particular procedure (Neches, Langley, & Klahr, 1986), and organization of search control knowledge into domain-appropriate methods (Newell, 1980; Card, Moran, & Newell, 1983). At the early stages of learning, problem solving behavior precedes the development of cognitive skill. Practice in the skill transforms this problem solving behavior into skilled cognitive performance. Here I present results of a more fine-grained analysis of this type of behavior for certain types of basic level skills the student of a command language needs to acquire. The most basic level procedure identified in LOTUS 1-2-3 is the TYPE-ENTER method for entering label or numeric data into the spreadsheet.

```
TYPE-ENTER METHOD
    SELECT-COLUMN/ROW
    MOVETO-COLUMN/ROW
    TYPE-DATA
    ENTER-DATA
```

Observation of a smooth, rapid execution of this method indicates that the individual is performing a cognitive skill. Subjects quickly learned this method and went from means-end analysis to a 'repeated successful' strategy for

this particular procedure with little problem. No questions were needed to clarify understanding about this procedure after the instruction and practice session prior to the experiment.

However, each spreadsheet had a few subgoals which were more difficult than the others. These more advanced level subgoals were all similar in that they required a label-prefix (a special symbol in LOTUS 1-2-3) to be typed in prior to the contents of the subgoal in question. Analyzing the solution part attempts and strategy shifts for these subgoals provided more detailed insight into the changes in problem solving behavior subjects employed as they autempted to solve these more challenging problems.

Anderson (1985) reports that there should be declarative interference between performing a skill and remembering similar knowledge before proceduralization of the knowledge. This appears evident in the protocols, especially for the more challanging subgoals. Subjects began by applying a means-end analysis to solve the subgoal problem. In the sample provided below, entering a numeric-alphanumeric data type codmbination, typing a special operator before the data type is required. All but one subject forgot the label-prefix concept, or were not certain of how to use it. This particular operator, presented in the tutoring session prior to the experiment, was essential in order to obtain this subgoal. Although there isn't enough data to represent other than qualitatively, subjects generally entered a means-end, generate and test loop in an attempt to locate the correct solution path for this subgoal problem. Questions were asked at the boundaries of each solution attempt failure as current states were evaluated. Operator subgoaling was always used if a correct solution couldn't be located with a generate and test strategy. The questions were often followed by the subject's verbal reasoning about the failed strategy.

After the initial typing and entering "6 Month" into a cell address (means-end analysis strategy) and finding out that this doesn't work unless the "6" is preceded by a label-prefix, the following dialogue occurred:

	Dialogue	Strategy
		failed means-end
Q1:	I was wondering what I did?	
	((<Causal Antecedent><Action Space><Data Entry Node>)	
S1:	OK, I'll try again.	generate and test
S2:	I really don't understand this.	
S3:	One more time.	generate and test
S4:	I'm trying to think of another way to play with this.	operator-subgoaling

Q2: Why did it go there?

(<Goal Orientation><Action Space><Data Entry Node>)

At each strategy shift, the subject would apply various different operators or sequences of operations in an attempt to locate the correct solution strategy. This subject eventually broke up the subgoal into two separate subgoals and entered them each into a separate cell address on the spreadsheet. This method was not the correct solution, but did allow the subject to attain the subgoal state.

Control over search of the problem space depends on the kind of knowledge one has immediately available (Newell, 1980) and can involve applying knowledge stored in memory. If a goal state is impeded for want of an appropriate action or operator, the student can ask a question as a memory aid to gain the knowledge needed, and/or can apply weak-method problem solving strategies to attempt another solution path in the problem space. Remembering a solution strategy from a previous occurrence will serve to facilitate subsequent problem solving with similar subgoals. In another case, the subject remembered a similar situation from a previous spreadsheet in the trial. After the initial means-end analysis for entering a formula, the following dialogue occurred:

Dialogue	Strategy
	failed means-end
Q1: How come it didn't go in?	
(<Causal Antecedent><Action Space><Calculation Node>)	
Q2: Is there a reason?	
(<Verification><Action Space><Calculation Node>)	
S1: It must be the zeroes.	generate and test
Q3: How come it went in before and it's not here?	
(<Causal Antecedent><Action Space><Action Space>> <Calculation Node>)	
S2: Skip it. I'm going to get rid of that zero.	generate and test
S3: Well, I'll try again.	

After the failed means-end strategy, the subject asks a causal antecedent question indicating he fully expected the action he took to obtain the subgoal state. The next question is a verification type with the verb 'reason' implicitly indicating that the subject suspects this is a 'reason for' the action not working. The causal antecedent-verification pair of questions illustrates some

hypothesis testing about the failed strategy. Even though this subject was able to retrieve a solution strategy from memory that had worked on a previous similar subgoal (Q3: entering calculation data), unknowingly, he kept hitting a special function key that recalculated the formula and replaced it with a zero. Thus, questions can be used by students to retrieve and verify pertinent information for the task. However, if the actual behavior exhibited by the student is errant, the solution strategy will not be achieved.

Because the learning task was limited to controlled instruction and feedback, no dramatic, stable strategy shifts were observed over subjects. Simon and Reed (1976) suggest that gradual strategy shifts are indicative of learning and I think that the data here reflect the very first changes that occur as students learn the appropriate rules and operations that make up the best solution strategy. People attempting to solve problems, and faced with several choices of paths, may try several of these before a solution is found (Simon & Reed, 1976). This is especially true for novices and was observed when subjects first applied a means-end analysis and then shifted to a series of generate and test strategies when the first strategy proved unsuccessful. Although the goal state may not be met immediately, trying alternative solution paths can serve to strengthen more low-level, instantiated skill behavior (here the TYPE-ENTER method), and, perhaps lead to a correct solution. Of course the learner may not always be so fortunate and risks staying lost in an error state. Because the domain skill in this study is more complex than the Tower of Hanoi problem (Anzai & Simon, 1979) and other traditional problem space domains, this strategy transformation process should naturally take longer to develop. More instruction and practice in complex skill domains are required before stable strategy shifts can be observed and certainly considerably more experience is necessary before any skilled behavior performance can be expected to be observed.

Another indicator of learning in this task is to compare the number of subgoals expected to complete the task with the number of subgoals the subjects actually generated. The spreadsheets used in this study were very simple with a spreadsheet title, one column of label data (names of items), one or more columns of number data, and one or two calculations to be performed on the number data. Goal decomposition resulted in a total number of subgoals for each spreadsheet. Although the total number might vary between the spreadsheets, the types of subgoals were common within spreadsheets. Most of the errors were committed because of simple typographic errors, and omitted portions of the spreadsheet. The omissions were presumably due to how the subjects visually 'chunked' the spreadsheets, however, this paper will not address chunking phenomena. Other errors were committed because the required operators were simply not available in the subjects' representation for the knowledge. Some of these subgoals were simply not attempted by subjects with them declaring, "I don't know how to do that so I'll go on." Further work is planned to discuss errors in detail. It is mentioned here to illustrate its impact on novices' overall learning rate. This data suggests that without positive reinforcement or remediation, error-generated subgoals can grow unchecked which can impose constraints on effective learning and foster misconceptions in understanding the skill knowledge. Although subjects could often find the correct solution strategy through a successful sequence of means-end analysis/generate and test

strategies, most often the correct solution path was not located until after several unsuccessful paths were tried. Clearly, this unguided practice is not an efficient learning strategy.

CONCLUSION

The results of this study indicate that a specific set of questions relevant to the domain of procedural skill learning does indeed exist. This question set comprises a series of question types for soliciting certain kinds of knowledge in an instructional setting that appear to play specific roles in the learning process. Problem solvers attempting to learn the structure of a given task can combine question asking with evaluation of individual performance behavior from previous similar problem solving situations to organize and understand task knowledge in a learning by doing paradigm.

Pedagogical questions function in general to identify a problem the student has with understanding a particular concept or procedure in the domain. Questions can also serve as memory cues when all of the information can't be retrieved when it is needed. To articulate a question, the student must be able to express what it is he or she needs to know. One basic assumption for the ability to do this is that the student has already acquired a significant body of knowledge.

A tripartite cluster of question types, procedural, goal, and causal antecedent, appears to function as the primary method for acquiring and understanding prerequisite task knowledge in early learning. Procedural questions were by far the most frequent question type generated in this study suggesting their importance for understanding how legal operators, actions, and procedures are used at the very early stages of learning. The knowledge element accessed in these procedural questions defines the higher level nodes in the representation that a particular question refers to. I suggest that procedural questions will retain a high frequency until basic task procedures become instantiated in the student's representation for the domain. A drop in frequency for this question type should identify the beginning of the proceduralization stage for the particular skill in question. Goal questions appeared to drop off somewhat dramatically after the first encounter with the task. These questions seem to be most useful to novices who are completely unfamiliar with a task. Once a basic orientation to the task as problem space is attained, goal questions no longer serve a pedagogical purpose. Goal questions were observed to refer to overall task goals and did not function in acquiring knowledge about the domain's organizational goal structure. This question type occurs only at the beginning of learning as a task orientor for novices. I suspect the same question asking behavior will be true for experts when faced with a difficult or novel problem. Novices use verification questions alone to confirm what they think they know but are unsure of, and in conjunction with causal antecedent questions serving to refine reasoning about relationships between concepts and to test hypotheses about skill behavior. Miyake and Norman (1979) suggested that students who are capable of generating and testing hypotheses are in the process of actively constructing some type of organizational structure for the knowledge. The use of a verification-causal antecedent questioning sequence offers evidence in support of this claim. Use of this sequence of questioning should appear more frequently when students are structuring a particular knowledge element. I

think this type of questioning will become more prevalent in the intermediate stages of learning as students begin to proceduralize and organize the declarative knowledge obtained at the the beginning level of instruction.

Other more infrequently asked question types may simply not be needed by novices. Feature specification and concept completion questions may only have pedagogical usefulness to the student after a sufficient body of knowledge has been acquired and a basic organizational structure formulated. The appearance of these question types in conjunction with the knowledge element the student wants to know about should reflect when in learning a particular area of knowledge requires refinement and tuning.

Results from this study may also have implications for a theoretical basis of the psychology of question asking in a procedural skill domain. Belnap and Steel (1976) and Harrah (1973) argue for the need to analyze the logic of questions. Here I present some preliminary data that begins to evaluate the psychological logic of a set of pedagogical questions used to acquire and organize a particular kind of skill knowledge. As a theory of pedagogical question asking develops, we can begin to understand the nature of questions, their purpose in instructional environments, and their implications for defining knowledge states. The classification and analysis of questions asked throughout various stages of learning should facilitate our understanding of how and what kind of questions are used at different levels of learning. A more precise identification of the specific kinds of knowledge a student needs during the various phases of the acquisition process should lead to a more rapid transition from a problem solving mode to practiced cognitive skill performance.

Understanding question asking and its role for defining student knowledge states is important for developing more effective instructional strategies. One effort in this regard is the current research in intelligent tutoring systems. For the tutoring system to be most effective, it must know the student's knowledge state so that the tutor can monitor and deliver appropriate instruction. A formalism for representing pedagogical questions might help the representational problems surrounding student-tutor dialogues in these systems. One example is a system, MARVIN (Sammut & Banerji, 1986), that understands and answers verification questions for simple concept learning. Tutoring systems need to know how much and what kind of information the student knows before an appropriate response can be given. If the tutoring system can interpret the knowledge state from the types of questions a student asks, than an appropriate answer is possible. However, much work needs to be done in this area before robust dialogue systems in intelligent tutors become a reality.

SUMMARY

The research described in this paper has been undertaken in order to investigate the role of question asking during procedural skill acquisition. The approach taken to interpret the meaning of the questions has attempted to analyze the questioner's discourse goals through a conceptual categorization method within a specific context. From the preliminary data analysis, one can see evidence of an emerging question set inherent to the domain. Interpretation of the type of questions asked as well as their placement within the

instructional context appears to provide information that is useful for dg-scribing a particular knowledge state. Understanding the function of questions during learning and how to interpret their meaning may be useful for the development of dialogue systems in intelligent tutoring systems. Continued research is necessary in order to elucidate further the question system in learning, its implication for knowledge representation and how understanding questions can improve instruction as well as skill acquisition.

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APPENDIX A. SPREADSHEET USED AS STIMULUS MATERIAL WITH SUBGOAL DECOMPOSITION

AVERAGE UTILITY
= = = = = = = = =

Month	Utility Cost	6 Month Average
= = = = =	------------	------------
January 1982	6500	
February	6700	
March	6400	
April	5700	
May	4900	
June	4100	5770
July	4300	5350
August	4500	4980
September	4200	4610
October	4700	4450
November	5100	4480
December	5800	4760
= = = = =	------------	------------
Averages	**	**

**(Create a formula or function to average numbers in these columns)

TOTAL SUBGOALS = 47
Alphanumeric = 17
Numeric = 19
Alphanum/num combo = 2
Symbols = 7
Caluclations = 2